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GERMAN CENTIMETRIC WAVE TECHNOLOGY AT THE END OF WORLD WAR II

By

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EDITOR'S NOTE

The achievements of British scientists in the field of radar research and development for operational use played a potent part in the defeat of the German Wehrmacht. On the German side, too, there were a number of able scientists who were keenly aware of the importance of winning the radar war, but, in contrast to the situation in this country, the higher authorities of the German State did not give them full support. An early but striking example of this failure to appreciate the importance of radar is afforded by Goering's decision, on 15th August 1940, that air attacks on British radar sites should be discontinued "in view of the fact that not one of those attacked has so far been put out of action" (In fact, the station on the Isle of Wight had been severely damaged on 12th August, but this had apparently gone unnoticed by the Germans).

Professor Leo Brandt was one of the leading German radar experts during the War and is now a senior official in the North Rhine - Westphalian Ministry of Economics and Transport. His lecture to the Radar Conference held in Frankfurt in 1953, under the auspices of the Committee for Radio Navigation, described the German efforts in the field of centimetric radar. Some explanatory footnotes have been added.

THE STATE OF GERMAN CENTIMETRIC WAVE TECHNOLOGY AT THE END OF WORLD WAR II

(Professor Leo Brandt)

We are at present holding a meeting of experts and people interested in the civil radio-navigation service. During the next two days we will hear highly-qualified scientists and specialists speak on the subject of the magnificent new safety systems and their employment to provide the maximum degree of safety for the enormously increased scale of air traffic. One might ask why the distinguished preceding speaker (1) dealt with the military radar equipment of the war years at this meeting and why it is also my intention to report further on the final phase of radar techniques in Germany in the Second World War. If such a question be raised it must be clearly understood that throughout the ages, and thus in recent times as well, it has been possible to utilise technical installations to the same extent for both peace and war, taking the torch which the warrior of ancient times threw into his enemy's hut as a point of departure.

Radio has extended the function of an important human organ, the ear, as far as may be desired. Any ship or aircraft can be contacted, Buenos Aires can be reached by telephone and an entire nation can be addressed by its government by means of the radio. Radar techniques, which we have heard about in Sir Robert Watson-Watt's excellent lecture(2) and whose history in Germany has been outlined to us by Dr. Diehl, have now extended the function of the even more important human organ, the eye, to the limits of what may reasonably be desired. With radar installations it is possible to see at night and in fog and to see all around, whereas the human field of vision is limited to 11° and one cannot see backwards as a matter of course. With the aid of radar we can determine range to within a few metres irrespective of the distance involved and, in general, the range extends to the limits imposed by the radar horizon. I have just said "of what may reasonably be desired". It would naturally be desirable to see far beyond the horizon but, in view of the present state of our knowledge, this does not appear to be attainable as a regular procedure and occurs only in isolated instances.

Whether the two possibilities offered by radio and radar of extending the function of the most important human senses to such a huge degree are used by mankind for peaceful or warlike purposes is a matter far beyond the technical field itself and this can be made clear at once by stating the case that the human eye itself can be used to align an enemy in the sights of a rifle. With regard to aviation, the public is fully aware of the difference between civil and military aircraft. The supreme importance of civil aviation is recognised by all and the sight of a modern trans-ocean passenger aircraft dces not give rise to thoughts of a military nature. At the moment this is certainly not the case with regard to rockets. These are generally regarded as purely military devices - as weapons - although there is no doubt that the time when large-scale rockets will be used for the peaceful purpose of transporting mail and cargo across oceans is imminent.

(1) Dr. H. Diehl: "On the history of radar in Germany, with special reference to its application in radio-navigation."

(2) "Resumé of the Origin, developments and applications of Radar in Great Britain."

Thus, if one is concerned with the state of technology in a particular field it is clearly essential that this technology be regarded as a single entity irrespective of whether it is applied in one form or another for civil or military purposes, and for this reason we must be guided by a number of striking precedents in the part of the meeting devoted to radar. In so doing we must appreciate that owing to the supreme importance of extending the two human senses, development has been promoted to a very considerable extent by military requirements.

I have spoken of technology as a single entity and at this point I wish to make a brief reference to the part played by technology in the modern industrial state. After the war there was a period in Germany in which technical development was regarded as being jointly responsible for preceding political events. At this time some said that we should take less interest in technology and more in higher national ideals. Others were of the opinion that technology had served the state too well and should have greater independence. Thus, there arose a certain resentment against technology and this still exists to some extent today in many spheres of our political life. We must clearly recognise at this juncture that an attitude such as this is extremely dangerous. Prior to the commencement of industrialisation in Germany the nation was far less populous than at present and the conditions of the working class were wretched in the extreme. The great Prussian statesman Hansemann, who rose to power as a result of the initial phases of industrialisation in the city of Aachen, said at that time that it was a blessing that the workers died so young for otherwise the survival of the human race could not be ensured. In actual fact malnutrition was rife and at that time the average expectation of life was about 30 years. The industrialisation which has taken place since 1850 has enabled Germany to support three times as many people at the present time. Since 1950 we have been faced with the task of bringing about a further appreciable increase in this development and of raising productivity - output per man - by 200 to 400% in order to achieve parity with American industrial efficiency. The continued existence of our nation, which is obliged to import 50% of its food, cannot otherwise be assured. Thus, a vital and absolutely decisive contribution is made by technology, which must be recognised and supported in all its fields by industry, science and the state alike.

Germany achieved much in the field of radar in direct competition with Britain and Sir Winston Churchill in his memoirs indicates that the standard in Germany was at least equal to that of British radar at the beginning of the war, as he mentions a technically well-developed German radar system at that time. This referred to the fact - which has been clarified in detail by Dr. Diehl - that from the outset the wavelengths used by German radar installations were appreciably shorter than the British and, moreover, that the choice of the 50-cm wavelength, which was also selected as a kind of standard wavelength for point-to-point communications and other tasks in the signals field as a result of Professor Runge's excellent proposals, was so fortunate that, technically speaking, there appeared to be no necessity for further probing into new fields of radar research. Nevertheless, the authority consulted by the Luftwaffe Chief of Staff at that time for the purpose of obtaining expert co-operation on the subject of the Flak artillery's tactical and technical requirements (Director of G.A.F. Signals)(1) had already requested the centimetre wavelength for the proposed Flak firing device which was later developed from the "Würzburg"(2) as a further step which would probably be necessary to achieve the high degree of accuracy required for firing. In spite of the high British opinion of the standard of German

(1) General Martini, who remained in charge of the Luftwaffe Signals organisation throughout the War.

(2) Ground radar system used for controlling searchlights, Flak and night fighters.

technical development, there existed one vital difference between the two nations, namely that this development, the effectiveness of which was regarded as significant, was integrated and given decisive encouragement in Britain at the highest level as a result of Winston Churchill's personal interest in this field.

No such encouragement or integration existed under the German State leadership. Indeed, both at the outbreak of and during the war its principal directives even had an exceptionally restrictive effect on the progress of development inasmuch as the necessity for long-term development projects was repeatedly disregarded on the basis of assessments of the general situation and the completion of tasks which had nevertheless been set was made impossible by the removal of specialists. Despite the State leadership's unfavourable influence on technical development at that time - a factor to which I will merely refer at this juncture and deliberately refrain from developing as a controversial issue, which could easily be the case - much was achieved in the field of radar both in the sectors of scientific research and industrial development, although at the outset no assistance whatsoever was forthcoming from an integrating authority. Indeed, we were constantly obliged to act on our own initiative and simply transfer the personnel required from other research and development projects being undertaken in the unusually extensive field of radio development with its innumerable completely new requirements. Our activities in the field of radar, which had been staunchly pursued in this manner, then received an abrupt shock. Daring British Commandos raided a Würzburg site on the Channel coast near Dieppe(1) and, after a gallant defence by the small garrison, half of which was lost in the action, captured the frequency-governing components of the installation, the wave-guide and the antenna. From this moment onward we assumed that the enemy would take measures against our radar. We were absolutely correct in foreseeing jamming transmitters and decided upon the exceptionally difficult task of changing the wave-lengths of every radar installation from the northernmost point of Norway to Africa and making them capable of frequency variation. We also foresaw the employment of "Window", but after considering the risks involved in major research into this field being revealed to the enemy by means of espionage and in not developing counter-measures at all, this line of research was not pursued.

A few weeks before this event, at the end of December 1941, Goering permitted an almost complete integration of radar activity - at least within the Luftwaffe - under the control of the Director of G.A.F. Signals, although unfortunately this situation lasted for only about 18 months. Close co-operation between all service departments interested in radar and science and industry was ensured by the constant personal participation of the Director of Naval Signals and other naval experts and OKW(2) representatives in the Luftwaffe conferences which were held every week or fortnight at Potsdam-Eiche. Realising the necessity for intensified efforts in the field of development, the Director of G.A.F. Signals immediately promised to postpone other important G.A.F. Signals projects and make up to 15,000 signals specialists available for research, development and production. At the same time technical specialists were released from industry to direct various development groups by the Air Ministry Technical Office and were later taken over by the Commissioner General for Technical Signals Equipment, General Fellgiebel. Development of remote-control techniques was directed by my respected colleague Professor Runge, navigation by Dr. Kramar and radar equipment by myself.

(1) This refers to the raid on Bruneval, near Le Havre, during the night of 27/28 February 1942.

(2) Oberkommando der Wehrmacht - Supreme Command of the Armed Forces.

With the assistance provided by the Director of G.A.F. Signals, development group leaders were able to specify the scale of development requirements - the Commissioner General for Technical Signals Equipment being informed that the radar programme depended on the release from the forces of 9,000 electrical engineering specialists, all of whom were allocated to development centres - and it was then possible for work to be undertaken on a broader basis despite considerable initial training difficulties. This phase was also implemented, but - most regrettably - no work was undertaken in the centimetric field because of the belief in various scientific circles that, owing to the similarity to conditions existing in the case of light rays, centimetric waves, on striking objects such as ships and aircraft, would be diverted away from the source so that there would be insufficient signal reflected directly back to the ground radar station. This fear that centimetric waves would break away was in fact, shown to be justified, although in quite another place (England). There it proved to be an unusual and unexpected gift of nature for enterprising techncians.

We have heard Sir Robert Watson-Watt speak of British efforts in the field of centimetric waves, the range of which over water was very much greater than that achieved by the longer waves previously used. As focussing was too sharp for searching with a fixed antenna, it was necessary to rotate the latter and use a plan-position-indicator as a screen. E.P. Rowe's book "One Story of Radar" gives a dramatic description of what happened when one of the first experimental sets was inadvertently left switched on over land on the homeward flight from a sea reconnaissance operation. To his astonishment, a technician who happened to glance at the screen saw the characteristic winding of the River Severn. The surface of the water had in fact allowed the centimetric rays to reflect away from the airborne radar so that nothing came back from this point, and in this way the contours of the river came out clearly. The result was a variable reflection of the radar rays in conformity with the image of the earth's surface, at least as far as areas of water were concerned. However, owing to the adumbration of fields, hills and blocks of houses, extremely characteristic differences between a city, open fields or a hill also resulted. As soon as radar waves were brought to bear on objects such as aircraft or ships this breaking away, which occurred in the case of areas of water and had led the Germans to regard the employment of radar waves as apparently impossible, in fact proved to be insignificant. On the contrary, the previously unknown but later very easily explicable fact emerged that such objects transmitted a considerably greater reflected energy back to the radar installation for the simple reason that the echoing area of these objects was proportionately far greater in the case of these very much shorter waves. It is now a recognised technical fact that centimetric waves are particularly suitable for reflection purposes.

E.P. Rowe writes that immediately after the sensational chance occurrence described above was made known, it was realised in Britain that there now existed a means of navigating aircraft independently of home-based navigation transmitters, the range of which, in the case of the "Oboe" system for example, was limited to the eastern outskirts of the Ruhr. Against the advice of a number of British experts, who were concerned that the new development might be disclosed, this latest device was very soon employed on flights deep into the Reich. After being shot down in the Rotterdam area and moved to the Telefunken laboratories, the sixth experimental device, on which the scribbled designation "Experimental Six" was still to be found, revealed that the British had undoubtedly adopted the centimetre wavelength and were even undertaking mass-production in this field. The device was severely damaged, the antenna and plan position indicator were missing and the purpose for which it was specifically intended was merely a matter of conjecture, but the revolutionary fact that these wavelengths were being employed constituted a serious menace for thoseresponsible for air defence and for the German Navy in particular. General Martini immediately convened a "Rotterdam" working party, which he placed under my direction, to consider the many problems which were now engulfing us.

First of all, the device itself was laboriously reconstructed. However, it was then extensively damaged by fire in an enemy bombing attack in March 1942 (1) which was, unfortunately, very successful and caused heavy damage at the Telefunken laboratories. The device was once again restored in a surface bunker in Berlin and, when put into operation on the roof, provided excellent images of the Berlin residential area and of the city's outskirts and lakes in particular. There now arose countless new problems in the fields of radar search, jamming and camouflage, all of the greatest urgency. It was now possible to explain the heavy U-boat losses sustained in preceding months, during which U-boat radar search installations did not obtain any response on a wavelength of 1.50 metres which, until then, was known to be the wavelength used by British aircraft search devices (ASV). Those present will never forget the oppressive and serious atmosphere which prevailed at the Eberswalde Naval HQ as a result of the losses which confronted us in the War Diaries at that time.

As the employment of the centimetre wavelength had been rejected in Germany owing to its presumed unreliability arising from the reflection factor, its use by the enemy was also not suspected. Technical progress had now reached a stage at which it was possible to make simple radar observation devices available to the Navy immediately. In spite of existing Luftwaffe requirements, development in the centimetre wavelength field had, it is true, been officially terminated several months before the Rotterdam device was discovered - no doubt being regarded as of no direct importance to the further development of signals devices and in ignorance of its as yet unknown but outstanding suitability for radar techniques as well as out of consideration for priority and the prospective duration of the development phase until readiness for operational employment was achieved - and the engineers and technicians concerned had been allocated to other projects. These were re-assembled and within the shortest possible space of time U-boats were issued with a device - Naxos 1 - the small antenna of which was held up in the U-boat's conning tower by a naval signaller. The range of the detector with a low-frequency amplifier was 8 km, which was generally sufficient to allow the U-boat to submerge a few metres just before the bombs hit the water. Later, with a larger antenna, ranges of up to 50 km were achieved, thus virtually eliminating the menace which H2S bombing constituted for U-boats.

For the Luftwaffe the employment of H2S (or "Rotterdam", as we called it) produced an entirely different situation from that which confronted the Navy in respect of its U-boats. Indeed, we expressed doubts from the outset as to whether the employment of such a device would do more harm than good to those using it, for in fact one might say that it provided a red light which need only be detected in order that it in turn might be recognised and attacked. Recognition was also vital in the case of U-boats, but naturally they could not take offensive action. The same Naxos device, but with a rotating antenna for automatic searching fitted outside the aircraft was immediately proposed. The prospects of this device were decidedly poor; the first person to be assigned to its development, an extremely capable

(1) This should be 1943. H2S, the device referred to, was first used operationally by Bomber Command on 30/31 January 1943.

development engineer, declined the task as hopeless. Many estimated its range at 3 km and, under these circumstances, it was not exactly pleasant to give Goering a personal recommendation that such a device might be operationally useful. However, the centimetre waves had a surprise in store for everybody concerned. This simple little device, fitted in a free-lance night fighter, in fact achieved a range of 50 km, thus confirming the "red light" theory beyond doubt. By the end of the war 1,500 German night fighters had been fitted with this device. The fact that only 50 of these aircraft were able to operate on any given night was due to the decline in synthetic fuel production from 500,000 tons in January 1944 to 10,000 tons in October 1944. This in turn was due to a considerable extent to the fact that there were insufficient day fighters available and that the vastly superior Me 262 jet fighters made their appearance two years too late, and then in only very small numbers, owing to the pointless delay caused by the high-level decision to produce an absolutely unnecessary bomber version of this type. The collapse of the hydrogenation plants was therefore mainly a question of insufficient day fighters without any specific radio control, although it must be mentioned that the Inspector of Fighters, General Galland, did his utmost to resist this fatal trend even to the point of incurring extreme disfavour.

What effect did the "red light" theory have on ground detection? On the ground it was possible to use more powerful receivers and larger antenna systems than those provided by Naxos, an example of which is to be found in the Korfu receiver which Dr. Güllner undertook to develop at Blaupunkt as a result of decisions taken by the "Rotterdam" working-party. This device was finally employed throughout the entire wave-band from 2.7 - 18 cm in eleven different versions, which were combined in Kornax D/F installations. These produced such excellent results that H2S sets could even be detected when they were switched on to warm up at British airfields 20 minutes before the aircraft took off. From the moment they took off until the moment they landed again, the pathfinders leading the squadrons were completely under the surveillance of the Korfu network, which covered the entire defence zone of western Germany and was centralised in Berlin by means of a special communications network. One may well claim that during this period the employment of H2S was extremely useful to the German defence and we assume that this is why it was used much less frequently later on. Incidentally, all radar search installations mentioned so far were also operated on the 3-cm wavelength and were thus equally capable of picking up the 3-cm device (H2X) which we called Meddo after the place where it was found.

The employment of jamming transmitters had been considered at the very first deliberations on defensive measures, although the usefulness of these installations was regarded as highly problematical in many respects. Nevertheless, Siemens and Halske undertook this particular task and, with the assistance of Dr. Schultes, develpped the so-called Roderich jamming transmitters for the 3-cm and 9-cm wave-bands with an output of about 5 watts. Close-range jamming at 2 km was effective but at 10 km the source of the jamming could be clearly observed on the plan-position-indicator. The Reich Post Office Research Laboratory developed the Feuerball, a jamming transmitter with a continuous output of 100 watts and a parabolic beam antenna 50 cm in diameter, which could be directed at the H2S and appeared to be definitely effective, but as these installations were employed on only a limited scale it was not possible to jam an attacking force completely. Jamming installations with a peak output of 5 kw developed by Lorenz were employed effectively against the centimetre navigations system called "Oboe" by the British and "Bumerang" by us and the Korfu and Kornax radar search antenna and the jamming transmitters were successfully combined in the Korona installation.

However significant the potentialities of jamming might be within the framework of the radar observation service, it must nevertheless be realised at the same time that the employment of jamming transmitters is much more difficult in the case of progressively shorter wavelengths than with longer wavelengths, on which British aircraft jamming transmitters were very effective against Würzburg, Freya and Lichtenstein SN 2, as the jamming field remains constant on the hertz scale and the overlap coverage is therefore proportionately smaller with higher frequencies and, moreover, assuming that the radar device to be jammed has different or variable wavelengths, the number of jamming transmitters required is thus appreciably greater.

Two projects which from the very first appeared to offer greater prospects of success than the jamming measures taken against H2S and H2X were the fields of camouflage and deception. The possibilities offered by deception were probably more important and deception devices were particularly effective when used at sea. At the suggestion of Dr. Kühnhold, these devices were called "Bolde" from the word Lügenbold (meaning habitual liar). Their reflections simulated those of a U-boat or a small ship exactly and if, therefore, several were employed to protect a U-boat there would be little probability of the latter being discovered among the "Bolden". At the suggestion of Dr. Roosenstein, U-boats also discharged deception antennae from their torpedo tubes, a measure which was given the code-name "Thetis". All in all one may well assume that the further development of this technique also contains many possibilities for the civil field, as beacons comprising triple reflectors or other types of antennae could provide strikingly clear checkpoints for ships' radar along coastlines or at entrances to ports without the necessity for transmitters and sources of electric power.

At this point mention must be made of a project in which Dr. Kühnhold was particularly interested, namely the camouflaging of the U-boat's Schnorchel, which was given the code-name "Schornsteinfeger" (chimney-sweep). This camouflage device reduced the range of the enemy's radar by about half and, although this may appear to be insignificant at first sight, it increased the enemy's search effort fourfold and thus undoubtedly constituted an important advance.

At this juncture the Navy set up a controlling technical body in the shape of the Scientific Operations Staff, which was directed by Professor Küpfmüller and resulted in a comprehensive and extremely effective centralisation of technical requirements at high level.

The combined field of radar observation and jamming are also called the technique of direct radar warfare because in this case a campaign was carried on, without recourse to offensive weapons of war, between radar devices, radar observation installations and jamming transmitters. Deception devices such as "Window" and "Bolde" were naturally included in this sphere. However, this strange form of warfare, in which the radar installations themselves were the weapons, was capable of attaining considerable military importance, as Dr. Diehl informed you in connection with the battleships' breakthrough in the Channel.(1)

Offensive radar devices are of course the real objective of the radar engineer's development work and for this reason some reference will now be made to the technical state of development of these devices in the last year of the war. Developing offensive radar devices was as difficult as

(1) The escape of the German warships Scharnhorst, Gneisenau and Prince Eugen through the Channel 11 - 13 February, 1942.

putting radar search installations such as Naxos and Korfu into operational service was easy. The initial objective in the field of application was restricted to the ground observation device, that is to say the German H2S, which was called the Berlin and developed in conformity with the much more limited amount of space available in small German aircraft types such as the Me 110 or Ju 88, which contrasted ludicrously with the exceptional spaciousness of the enemy's heavy four-engined bombers, which were comparable with express railway coaches.

However, as the era of potential German bombing attacks progressively faded and a definite trend towards a defensive phase occurred, the military importance of this project proved to be insignificant. The radar installations employed by the aircraft reporting service, the Flak and for night fighter operations, that is to say the Freya, Würzburg, Riese and Lichtenstein SN 2, were of decisive importance to a defensive policy. However, as has already been described, the belief that centimetre wavelengths were not suitable for employment in these devices still existed. The fact that they were suitable for ground observation devices was regarded as proof of the correctness of this theory, bearing in mind that the earth itself is of course the greatest reflector of all and would in any case always give sufficient reflection energy.

Nevertheless, a centimetre device was fitted in a Würzburg, rather from a general desire for knowledge than as a result of any specific development project, and the first test against an aircraft was carried out at the Erika bunker laboratory at Wittenau on 22nd December 1943. The range was estimated at 8 km. However, the normal Würzburg range of 30 km was achieved, thus completely changing the attitude towards the usefulness of centimetre waves for offensive radar installations, which was of particular importance as the efficiency of most first-class German radar devices had begun to be seriously impaired by jamming transmitters and "Window" during the preceding 5 months, that is to say since the attack on Hamburg.(1) A scheme for the modification of all offensive radar installations to the 9, 3 and 1-cm wavelengths was thereupon worked out during the Christmas of 1943 and, at the beginning of January 1944, was submitted to the Director of G.A.F. Signals, the Air Officers commanding the various branches of the Luftwaffe, Admiral Stummel and his Staff and leading industrialists at a meeting presided over by Field Marshal Milch. In the case of 9-cm installations this scheme was carried out to the extent of putting almost every type into operational service, on 3 cm practically every installation had been prepared for and was in production, whilst on 1.5 cm a radar device to fire Flak rockets at the required range was ready for installation in the wings of jet fighters. When this device was tested against an aircraft from the roof of the Humboldthain bunker a range of 2 km was definitely confirmed which, with the small antenna, was therefore appreciably in excess of requirements. Moreover, tactical and technical requirements necessitated a transition to the field of millimetre wavelengths and Professor Esau, who had frequently outstripped the rest of the technical field in the race for short waves, had produced wireless listening receivers operating on wavelengths down to 4 millimetres. Large-scale panoramic installations to succeed "Jagdschloss" were developed at the same time by Siemens and Halske and Telefunken. These installations, for which normal transmitters with a high-level peak power of 20 kw and high-powered transmitters with an output of 100 kw were available, were ready for action at Brück in Brandenburg.

(1) "Window" was first used operationally by Bomber Command in the raid on Hamburg on 24/25 July 1943.

The "Egerland", which was devised for the Flak and comprised the "Kulmbach" panoramic device and the "Marbach" firing device, was a particularly successful development. The accuracy of this device as regards altitude and direction was considerably higher than that of any other Flak installation and, in the case of the latter, was generally in the region of one sixteenth of a degree. In our opinion the advantage of this device was to be found in the fact that for tactical firing the component battery's panoramic installation provided a complete survey of the air situation with a radius of 50 km. Thus, by allowing the firing device to sweep semi-automatically, it was possible to select an apparently suitable target, engage it, and then switch very rapidly to another target according to tactical expediency or necessity. With the Würzburg the selection of a target was purely a matter of chance, for there was no possibility of choosing which out of a number of available targets was the most suitable to engage.

Moreover, another great advantage was derived from the important two-fold function of this installation. Even large quantities of "Window" such as those which were clearly identified during the mass attacks on Berlin were not able to blanket the "Kulmbach" panoramic device, for the aircraft always appeared as brilliant specks in the cloud of "Window". The firing device, whose beam concentration of one degree would never have permitted a search and which instead had recourse to this semi-automatic method of alignment, could then be trained on these specks. Even the large quantities of "Window" which were employed at that time were not able to fill the narrow beam completely and this installation was therefore absolutely proof against "Window" jamming even without "Doppler" effect attachments such as the "K-Laus" or "Würzlaus". It must of course be borne in mind that "Window" was at that time cut to 50 cm and not 10 cm and was therefore 25 cm and not 5 cm long. However, according to precise calculations which have since been made by Dr. Stepp, jamming would not have been as effective as it was in the case of the "Würzburg" even with 5 cm "Window", primarily because provision had been made for the attachment of "Doppler" effect equipment which, in the case of the "K-Laus", had been proved to reduce the effect of "Window" in a ratio of 1 : 10.

The Berlin N night fighter device which found operational employment with Night Fighter Geschwader 1 at Gütersloh in March 1945, was responsible for the destruction of 10 enemy aircraft. In these operations the stick control of the reflector, which clearly indicated the evasive movements of a bomber which suspected that it was being pursued, was considered particularly effective.

The principle of proceeding step by step had been implemented with extreme care in the case of all installations included in the scheme, the same steps being taken with Navy and Luftwaffe devices alike. The Navy had a "Berlin S" installation with a large antenna attached to the masthead aboard the "Prinz Eugen" and a number of these devices equipped with a small antenna was supplied to E-boats. In the latter case this device proved its usefulness when an E-boat was obliged to lead 100 small vessels with 20,000 refugees aboard through a 100-metre wide channel in a minefield outside a Pomeranian port at night and under a Russian bombardment an operation which succeeded only because the minefield buoys could be clearly identified by the E-boat's "Berlin S".

Two U-boats were equipped with a radar periscope which, when raised, enabled them to carry out location while moving underwater. The technicians and crew reported how surprisingly good location was from the very first moment the radar periscope broke through the surface of the water and a commander said that he felt as if he were in a helicopter 200 metres above his submarine as convoys, single ships, buoys and coastlines could be clearly identified at ranges of up to 15 - 20 km.

In view of its many coastal defence commitments, the Navy immediately attached importance to coastal stations operating on centimetre wavelengths. GEMA therefore equipped a number of "Seetakt" coastal observation posts with "Würzburg" reflectors and a 9-cm "Berlin" installation. These installations were called "Renner" and were able, for example, to track a group of five British small craft up to a range of 32 km. "Riese" installations fitted with Berlin 9-cm devices achieved particularly good results and were able to pick up the mastheads of ships at ranges of up to 70 Km. Very good results were also obtained by centimetre radar tests in which an automatically rotating antenna and plan-position-indicators were employed for artillery fire control, as the position of the shell splashes could be identified quite clearly and only one correction was necessary to enable the artillery to fire for effect.

At this juncture it should not be forgotten that the centimetre radar equipment employed by the navies of Britain and the U.S. at this time was of an absolutely first-class technical standard and its achievements in naval warfare, particularly against the Japanese, have been prominently featured in war history. When the U.S. commenced production of armaments and entered the war the enemy's scope in all fields was increased to a quite exceptional degree, while in Germany space, material and manpower became increasingly restricted. Nevertheless, it may be of some interest to note that peak radar equipment output was achieved in December 1944, when 400 installations of the "Würzburg" type alone were produced and that a total of 500 centimetre radar sets was produced in April 1945.

A process which was developed particularly intensively by Professor Kohl the first step towards "seeing" by means of UHF waves - should not go unmentioned. The possibility of resolving the outlines of a ship by means of centimetre waves and a pierced cardboard disc had been demonstrated by Professor Runge as early as 1942. However, at that time the range was estimated to be very low, extending to only 1 - 2 km. In 1944 a Riese reflector at Pelzerhaken was fitted with a 9-cm installation, which enabled an object to be picked up in rectilinear form. In this way the raising and lowering of a lifeboat on a large ship could be clearly identified. Thus, the first step in this new field of seeing by means of UHF waves was accomplished, even if these experiments could undoubtedly no longer be of any direct practical interest.

Permit me to add a few words on the subject of valve technology.

Britain had taken the lead from Germany with the high-level pulse magnetron for centimetre radar installations, although very large magnetrons operating on the 20-cm wavelength and efficient 10-cm magnetrons were in the possession of Dr. Steimel and Professors Esau and Rukop respectively before the war The employment of German magnetrons in radar installations was not given consideration as, among other reasons, it was believed that they were prohibitively untunable and unstable. Later, work in the field of magnetron technology was resumed at high pressure.

To achieve tunability and continuous frequency change, the introduction of cavity triodes was proposed by Dr. Steimel at a very early stage. Cavity triodes operating on 8 - 10 cm developed by Schmied at Telefunken were employed in the "Pauke S" aircraft firing device. At this point mention must be made of two fields in which cavity triodes were also an urgent requirement. These belong to the technique of remote control and are, respectively, the V2 guide-beam control receiver operating on 20 cm, which was urgently demanded as a "Wireless gun-barrel" by General Dornberger and which, in elaboration of proposals made by Herr Muth, was nearing completion in the Gromoll department at Telefunken and the so-called "Kogge" relay stations in rockets, which were to have replaced "Kehl" and "Strassburg" stations and been employed in wireless-controlled flak rocket batteries, fighter rocket armament and remote-controlled bombs of the Hs. 293 and Fritz X type.

Last but not least, mention must be made of the particularly extensive effort which was necessary in the sphere of telemetry equipment. Altogether 24 different types of wavemeters, telemeters, measuring receivers, instrument leads, field strength meters, dynamometers, terminal resistances and dummy aerials were developed and made available. At the same time 49 devices were in the process of development in scientific institutes and industrial concerns. The radio navigation committee has managed to preserve a considerable amount of data on this subject and will shortly publish lists of these measuring devices.